Soil-Vegetation-Hydrology Studies
Volume II. A User Manual for ERHYM: The Ekalaka Rangeland Hydrology and Yield Model

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PREFACE

This publication contains results of Agricultural Research Service (ARS)-Bureau of Land Management (BLM) cooperative research conducted in southeastern Montana from 1968 to 1981. The publication is the deliverable product from the ARS to the BLM as specified in the cooperative agreement. It is presented in two volumes and an appendix.

> Volume I contains project history and background; summary research results; recommendations for field application of contour furrowing; recommendations for disposition of research facilities; and a bibliography of pertinent range research publications written by scientists at the Northern Plains Soil and Water Research Center, Sidney, Mont.
>
> Volume II is a User's Manual for the Ekalaka Rangeland Hydrology and Yield Model (ERHYM). It contains the model description; model documentation; input and output parameters; and an example of model use in which model output is compared with field measured data.
>
> The appendix contains a detailed listing of raw research data with no analysis or interpretation. Data included are: Hydrology and climate; soil chemical and physical characteristics; vegetation composition and yield; and soil water measurements by date and by soil horizon.

Copies of any of these volumes may be obtained by request to:

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VOLUME II. A USER MANUAL FOR ERHYM: THE EKALAKA RANGELAND HYDROLOGY AND YIELD AND MODEL

By J. R. Wight and E. L. Neff[1]

INTRODUCTION

ERHYM was developed to simulate runoff and herbage production for northern Great Plains rangelands. It is a range site scale model that provides daily simulation of runoff, soil water evaporation, transpiration, and soil water routing. Herbage yield is computed annually at peak standing crop. The model can utilize real-time climatic data to simulate ongoing processes, or it can utilize historical climatic data to simulate runoff and herbage production under a range of climatic conditions and management practices. It can run either on a seasonal basis, with new soil water boundary conditions required at the beginning of each year's growing season, or continuously, utilizing a simple snowmelt-temperature relationship to account for snowmelt infiltration and runoff. The model calculates infiltration and runoff from daily rainfall as described by Smith and Williams (*1980*).[2] The evapotranspiration (ET), soil water routing, and herbage yield calculations are from Wight and Hanks (*1981*).

DOCUMENTATION

Runoff

The runoff portion of this model as described here was taken directly from Smith and Williams (*1980*):

> The SCS curve number technique (USDA, Soil Conservation Service *1972*) was selected for predicting runoff from daily rainfall because (1) it is a familiar procedure that has been used for many years in the United States; (2) it is computationally efficient; (3) the required inputs are generally available; and (4) it relates runoff to soil type, land use, and management practices. The

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 17.

use of readily available daily rainfall is a particularly important attribute of the curve number technique. For many locations, rainfall data with time increments of less than 1 day are not available. Also, daily rainfall data manipulation and runoff computation are more efficient than similar operations with shorter time increments.

Traditionally, the SCS has used an antecedent rainfall index to estimate antecedent moisture as one of three conditions (I - dry, II - normal, and III - wet). The relation between rainfall and runoff for these three conditions is expressed as a curve number (CN). Each storm in a rainfall series is assigned one of the three curve numbers according to antecedent rainfall. In reality, CN varies continuously with soil moisture, and thus has many values instead of only three. Runoff prediction accuracy was increased by using a soil moisture accounting procedure to estimate the curve number for each storm (Williams and Hann *1976*). Although the soil moisture accounting model was found to be superior to the antecedent rainfall method, it did not contain a percolation component or a physically based water balance. Also, the model required calibration with measured runoff data.

Here the curve number technique was linked with evapotranspiration and percolation models to form a model capable of maintaining a continuous water balance. Calibration is not necessary, because the new model is more physically based. Besides predicting daily runoff volumes, an equation was also developed for predicting peak runoff rates. Tests with data from watersheds in Texas, Nebraska, Georgia, Ohio, Oklahoma, Arizona, New Mexico, West Virginia, Mississippi, Iowa, and Montana indicate that the model simulates runoff volumes and peak rates realistically (tables 1 and 2).[3]

Runoff is predicted for daily rainfall using the SCS equation

$$Q = \frac{(P - 0.2s)^2}{P + 0.8s} \qquad \text{if } P \geq 0.2s \qquad [1]$$

$$Q = 0 \qquad \text{if } P < 0.2s$$

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[3] All tables appear in the appendix, beginning on p. 19 .

where Q is the daily runoff; P is the daily rainfall; and s is a retention parameter, all having dimensions of length. The retention parameter s is related to soil water content with the equation

$$s = s_{mx}\left(\frac{UL - SM}{UL}\right) \qquad [2]$$

where SM is the soil water content in the root zone, UL is upper limit of soil water storage in the root zone, and s_{mx} is the maximum value of s. The maximum value of s is estimated with the I moisture condition CN using the SCS (USDA, Soil Conservation Service *1972*) equation

$$s_{mx} = \frac{1000}{CN_I} - 10 \qquad [3]$$

where CN_I is the moisture condition I CN. An estimate of the moisture condition II CN can be obtained easily for any watershed using the SCS Hydrology Handbook (USDA, Soil Conservation Service *1972*). [For operation of ERHYM, use the range site CN's reported by Hanson et al. (*1981*) in table 3.] For computing purposes, CN_I was related to CN_{II} with the polynomial

$$CN_I = -16.91 + 1.348(CN_{II}) - 0.01379(CN_{II})^2 + 0.000177(CN_{II})^3 \qquad [4]$$

If soil water is distributed uniformly in the soil profile, equation [2] should give a good estimate of the retention parameter, and thus the runoff; however, if the soil water content is greater near the surface, equation [2] would tend to give low runoff predictions. Conversely, runoff would be overpredicted if the soil water content were greater in the lower root zone. To account for the soil water distribution, a weighting technique was developed. The root zone was divided into seven layers and weighting factors (decreasing with depth) were applied. [ERHYM uses the appropriate number of genetic horizons rather than seven layers.] The depth-weighted retention parameter is computed with the equation

$$s = s_{mx}\left[1.0 - \sum_{i=1}^{N} W_i\left(\frac{SM_i}{UL_i}\right)\right] \qquad [5]$$

where W_i is the weighting factor, SM_i is the water content, and UL_i is the upper limit of water storage in storage i. The weighting factors decrease with depth according to the equation

$$W_i = 1.016\left[e^{-4.16\left(\frac{D_{i-1}}{RD}\right)} - e^{-4.16\left(\frac{D_i}{RD}\right)}\right] \qquad [6]$$

where D_i is the depth to the bottom of storage i and RD is the root zone depth. Equation [6] assures that

$$\sum_{i=1}^{N} W_i = 1.$$

The ET and percolation components of the model are described below. Since the model maintains a continuous water balance, mixed land use watersheds are subdivided to reflect differences in ET for various crops (range sites). Thus, runoff is predicted separately for each subarea and combined to obtain the total runoff for the watershed. Division by land use increases accuracy and gives a much better physical description of the water balance.

Peak runoff rate is predicted with the equation

$$q_p = 200(DA)^{0.7}(CS)^{0.159}\ (Q)^{(0.917DA^{0.0166})}\ (LW)^{-0.187} \qquad [7]$$

where q is the peak runoff rate in ft^3/s; DA is the drainage area in mi^2; CS is the mainstem channel slope in ft/mi; Q is the daily runoff volume in inches; and LW is the length-width ratio of the watershed. Data from 304 storms that occurred on 56 watersheds located in 14 states were used to develop equation [7]. Watershed areas ranged from 0.275 to 24 mi^2. Since these areas are larger than what is usually considered field-scale, the equation has variable exponents for DA and Q to accomodate areas down to 1 acre or less. These variable exponents simply prevent unreasonably high predictions for small areas.

Range site CN's in table 3, except for the thin claypan site, were developed and published in Wyoming (USDA, Soil Conservation Service *1978*). Hanson et al. (*1981*) compared several of the Wyoming CN's with CN's computed from actual watershed data (table 4) and found excellent agreement. The CN list in table 3 is probably the best available for application to mixed prairie rangelands.

A simple snow accumulation and snowmelt equation is used by the model taken from Stewart and others (*1975*). For all those days when precipitation occurs when the temperature is less than 0° C, that precipitation is stored in the form of snow. When snow storage exists and the temperature, Temp, is above 0° C, daily snowmelt (M) occurs, and input to the soil at the surface is calculated by

$$M = 0.18 \mathrm{Temp} \qquad [8]$$

unless M is greater than the amount of surface snow. Although this model is quite simplistic, it does help account for spring melt input, and would be difficult to improve without detailed daily temperature and radiation information.

Evapotranspiration and Soil Water Routing

The ET and soil water routing calculations are essentially the same as those used by Wight and Hanks (*1981*). Potential evapotranspiration (ET_p) is estimated with the equation Jensen and Haise (*1963*) used for calculating ET_p from a full cover of alfalfa with water nonlimiting for ET

$$ET_p = (0.014\ F - 0.37)R_s/580 \qquad [9]$$

where

F = daily mean air temperature in ° F

R_s = solar radiation in langleys

In this version of ERHYM, R_s is calculated daily from a general R_s curve for eastern Montana. The ET_p from native rangeland (ET_{pr}) is calculated as

$$ET_{pr} = ET_p \cdot \mathrm{CROPCO} \qquad [10]$$

where CROPCO is the range crop coefficient. The CROPCO used in this model was developed with lysimeter data from a mixed prairie range site in eastern Montana utilizing the relationship

$$\text{CROPCO} = \text{ET (lysimeter)}/\text{ET}_p \quad \text{(water nonlimiting)} \tag{11}$$

Potential transpiration (T_p) is calculated using the equation

$$T_p = \text{TRANCO} \cdot \text{RGC} \cdot \text{ET}_{pr} \tag{12}$$

where TRANCO is a site specific transpiration coefficient and RGC is a relative growth curve. TRANCO is related to foliar cover and standing live phytomass and represents the maximum portion of ET_{pr} that can be transpiration (T). For a loamy range site in eastern Montana that averaged about 900 lb/acre during the 12-year study period, TRANCO was determined to be 0.5. Using the same relationship between TRANCO and live standing phytomass as described by Ritchie and Burnett (*1971*) for cotton and grain sorghum, TRANCO can be estimated for various range sites on the basis of average yield (measured at ground level) by the equation

$$\text{TRANCO} = 0.0213 + 0.0162 \text{ (average site yield)}^{\frac{1}{2}} \tag{13}$$

A RGC developed from leaf area index data from Cottonwood, S. Dak. (Hanson *1973*) is used to indicate seasonal changes in standing live phytomass (fig. 1).

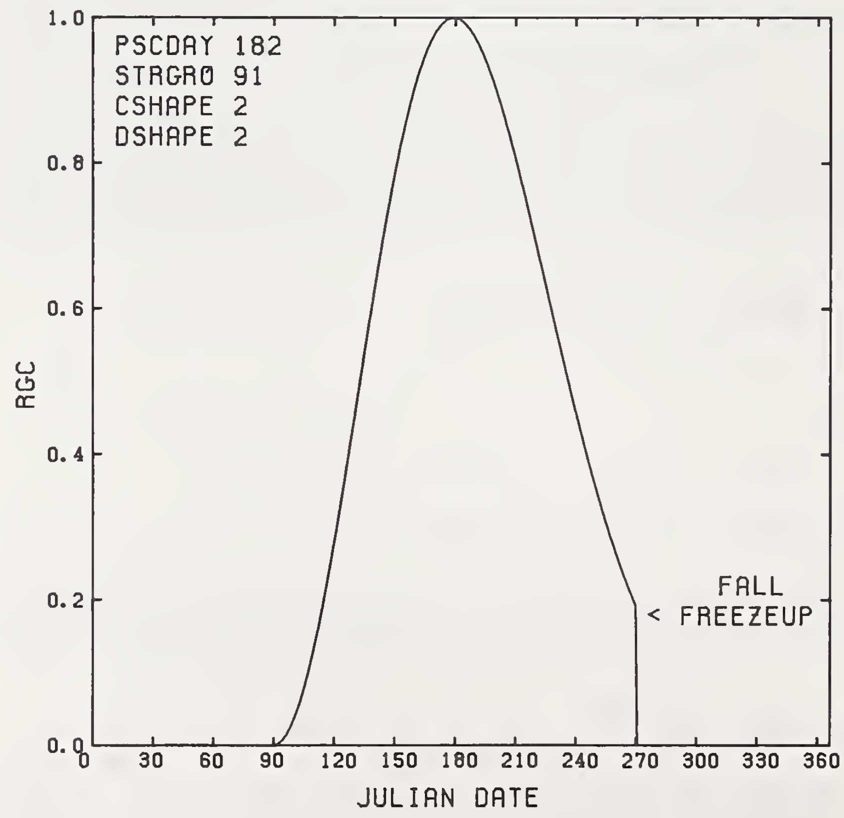

Figure 1.--Seasonal changes in the relative growth curve (RGC).

The RGC will vary from season to season and among climatic regions and range ecosystems. The RGC in figure 1 is described by a modification of the generalized Poisson density function reported by Parton and Innis (*1972*)

$$Y = \left(\frac{x-b}{a-b}\right)^{c} \cdot \mathrm{EXP}\left[\frac{c}{d} \cdot \left(1.0 - \left(\frac{x-b}{a-b}\right)^{d}\right)\right] \qquad [14]$$

where Y = seasonal growth expressed as a decimal fraction of 1.0
a = Julian day peak standing crop occurs (PSCDAY)
b = Julian day growing season starts (STRGRO)
c = a shape parameter for left side of curve (CSHAPE)
d = a shape parameter for right side of curve (DSHAPE)

For the curve in figure 1, the values of a, b, c, and d are 182, 91, 2, and 2, respectively. The day of growing season termination is controlled by a model input parameter and was 274 (October 1) for figure 1. Equation [14] provides considerable flexibility in describing seasonal growth for a wide range of climatic conditions. Examples of the flexibility are presented in figure 2.

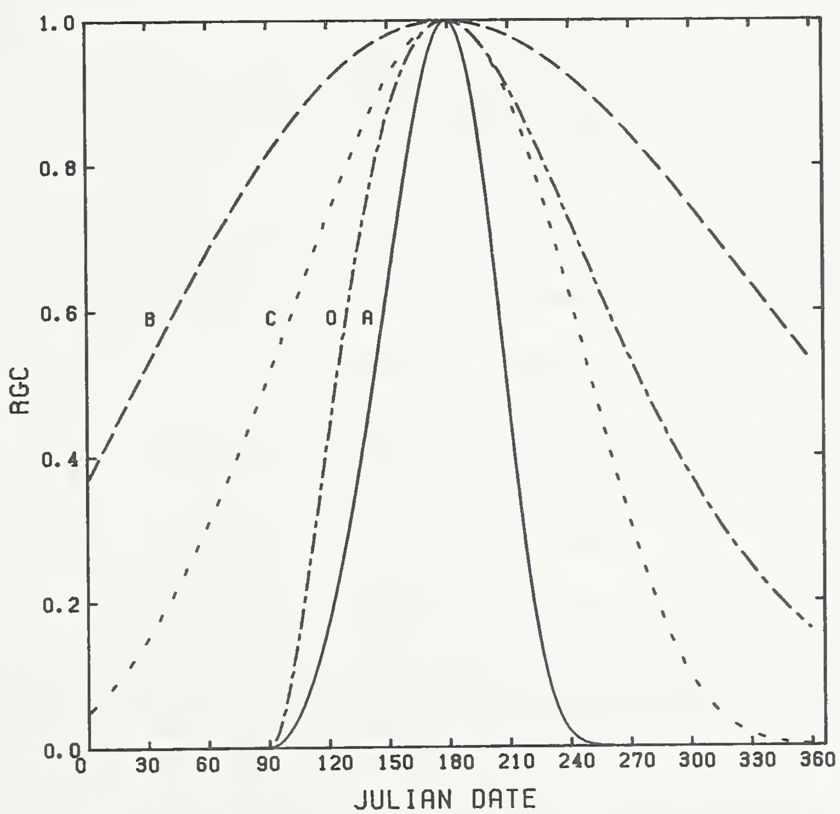

Figure 2.--Examples of the relative growth curves (RGC) that can be described by equation [14]. The Julian day for peak standing crop (PSCDAY) and start of growing season (STRGRO), left side shape parameter (CSHAPE), and right side shape parameter (DSHAPE) for curves A, B, C, and D, respectively, are 91, 182, 2, and 5; -120, 182, 2, and 2; -40, 182, 2, and 5; and 91, 182, 2, and 1, respectively.

Actual soil evaporation (E) is a function of potential soil evaporation (E_p) and time since the soil surface was last wet and is calculated as follows:

$$E = E_p / t^{\frac{1}{2}} \qquad [15]$$

where t = time in days since the last wetting of the soil surface

and

$$E_p = ET_{pr} - T_p \qquad [16]$$

Soil evaporation is limited to water in the top 12 inches of the soil profile that is in excess of air-dry soil water content, which is less than the lower limits of soil water availability (permanent wilting point).

Actual transpiration (T) is calculated by the equation

$$T = \sum_{i=1}^{n} T_p \left(ROOTF_i \; (SWS_i / AW_i) \right) \qquad [17]$$

where $ROOTF_i$ is a relative root activity factor for soil layer i; SWS_i is the available soil water in soil layer i; and AW_i is the available soil water storage capacity of soil layer i. The ROOTF for the top 12 inches of soil profile was considered to be 1.0, that is, temperature of this soil layer did not significantly affect T. For the 12- to 24-inch layer and greater than 24 inches, ROOTF values (fig. 3) were calculated from seasonal soil temperature curves published by de Jong (*1978*) for Swift Current, Saskatchewan, Canada, and root activity-temperature relationships developed by de Jong (*1974*) for a native range site in Saskatchewan, Canada:

$$SOILT_{(12-24)} = 11.75 \cos (2\pi((Day - 230)/365)) + 6.25 \qquad [18]$$

$$SOILT_{(>24)} = 10.25 \cos (2\pi((Day - 244)/365)) + 6.25 \qquad [19]$$

$$ROOTF = 0.0408e^{0.19(SOILT)} \; ; \; ROOTF \not> 1.0 \qquad [20]$$

where SOILT is soil temperature expressed in degrees Celsius.

As the model operates, water is added to the soil by precipitation and removed by E, T, and drainage. The soil profile is divided into genetic horizons, and water is added or subtracted from one soil layer at a time. If, following a rain, the water content of the surface layer exceeds field capacity, water is added to the next layer and so on until all precipitation minus runoff is accounted for or until all soil layers are filled. Excess soil water is counted as drainage.

Soil water extraction also proceeds one layer at a time beginning at the surface layer. If the surface soil layer cannot, under the imposed constraints, supply enough water to meet daily T_p, the model then extracts water from the second layer and so on until T_p has been satisfied or until all layers have

been sampled. If T_p cannot be satisfied from soil layer i, then the full T_p demand is applied to soil layer i+1, but extraction cannot exceed the difference between T_p and T from the preceding soil layers.

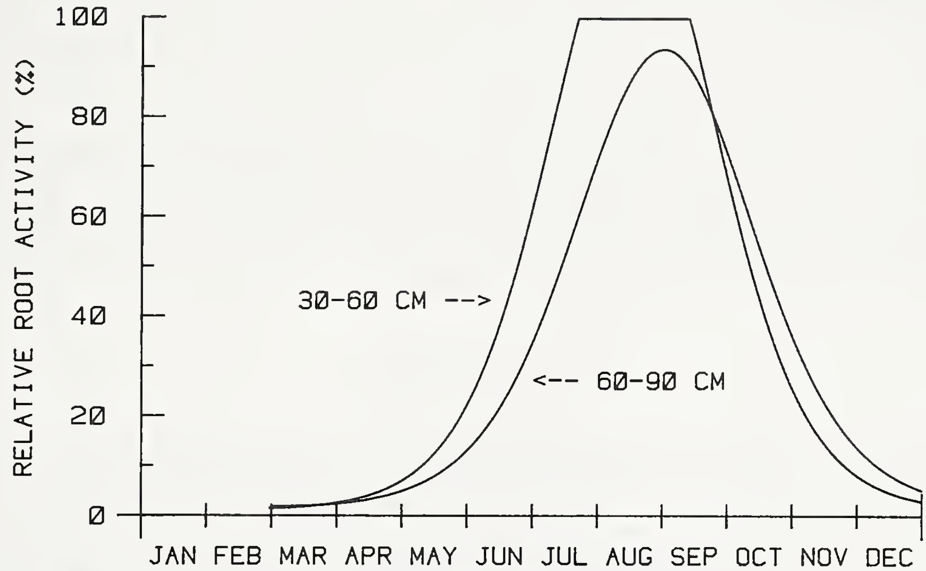

Figure 3.--Seasonal changes in relative root activities for the 30- to 60-cm and 60- to 90-cm (12- to 24-inch and 24- to 36-inch) soil layers (Wight and Hanks *1981*).

Herbage Yields

Annual herbage yield (Y) is calculated from T/T_p and the site yield potential (Y_p) by the equation

$$Y = T/T_p \cdot Y_p \quad [21]$$

Information concerning Y_p is not always readily available but can be estimated from the long-term average site yield by the relationship

$$Y_p = 1.5 \text{ (average site yield)} \quad [22]$$

Equation [21] tended to underestimate yields on the saline upland site, a very fine-textured site with high runoff. Under the most optimum climatic conditions for which the concurrent yields were considered as site or near site potential, T/T_p remained considerably less than 1.0. With high runoff, the soil water profile may never fully recharge, and yield may never reach potential. In such cases, some upward adjustments may be necessary when using equation [21] to predict yields.

The model can calculate a yield index which reflects the predicted year's yield as a fractional proportion of the long-term site average, equation [23], or a yield index which reflects the predicted year's yield as a fractional proportion of the site's maximum potential yield, equation [24].

$$\text{Yield index} = 1.5\ T/T_p \tag{23}$$

$$\text{Yield index} = T/T_p \tag{24}$$

The type of yield index calculated by the model is controlled by an input option. The index provides a good index of the growing season climate as it relates to plant growth and enables comparisons of range treatments or vegetation inventories among years or range sites by accounting for a large portion of climate induced variation in plant response.

Model Validation

ERHYM was validated using 5 years of Ekalaka field data that represented a range of annual precipitation and furrow age. The model was applied without any "fitting" of parameters or model functions; however, Ekalaka data was used to develop some of the CN's in table 3. The CN's were taken from table 3 with the range condition class calculated from field-measured yield data. The soil water parameters were determined from a 13-year record of field-measured soil water content data.

Comparisons of field-measured and model-predicted annual yield and runoff are presented in table 5. There is some discrepancy between field-measured and model-predicted yields, but most of the predicted yields fall within field-measured sampling error. The model effectively predicted herbage yields on the contour furrowed watersheds, and, as the yields increased, the percentage differences between model-predicted and field-measured yields decreased.

Based on the years of validation, the model effectively predicted rainfall runoff from the nonfurrowed watersheds. The differences between model-predicted and field-measured runoff values (tables 5 and 6) are probably as small as can ever be expected using CN's, Table 6 shows a comparison of model-predicted and field-measured runoff on a daily basis. As would be expected with using daily rainfall input, there are several discrepancies; however, there is fairly good agreement between model-predicted and field-measured runoff as to when the events occurred. Differences in runoff amounts evened out over the year.

The water-balance portion of ERHYM was tested against field-measured soil water data from site 2 for 1972, 1976, and 1980 (figs. 4 and 5). The water content at the 3- to 4-ft depth remained relatively constant throughout the year and was not included in figures 4 and 5. Generally, there was good agreement between the model-predicted and field-measured soil water profiles on both the nonfurrowed and furrowed watersheds. The differences in 1972 and 1976 on the nonfurrowed watershed can be accounted for almost entirely by the differences in the model-predicted and field-measured runoff during the early part of the growing season. Had the model-predicted and field-measured runoff been

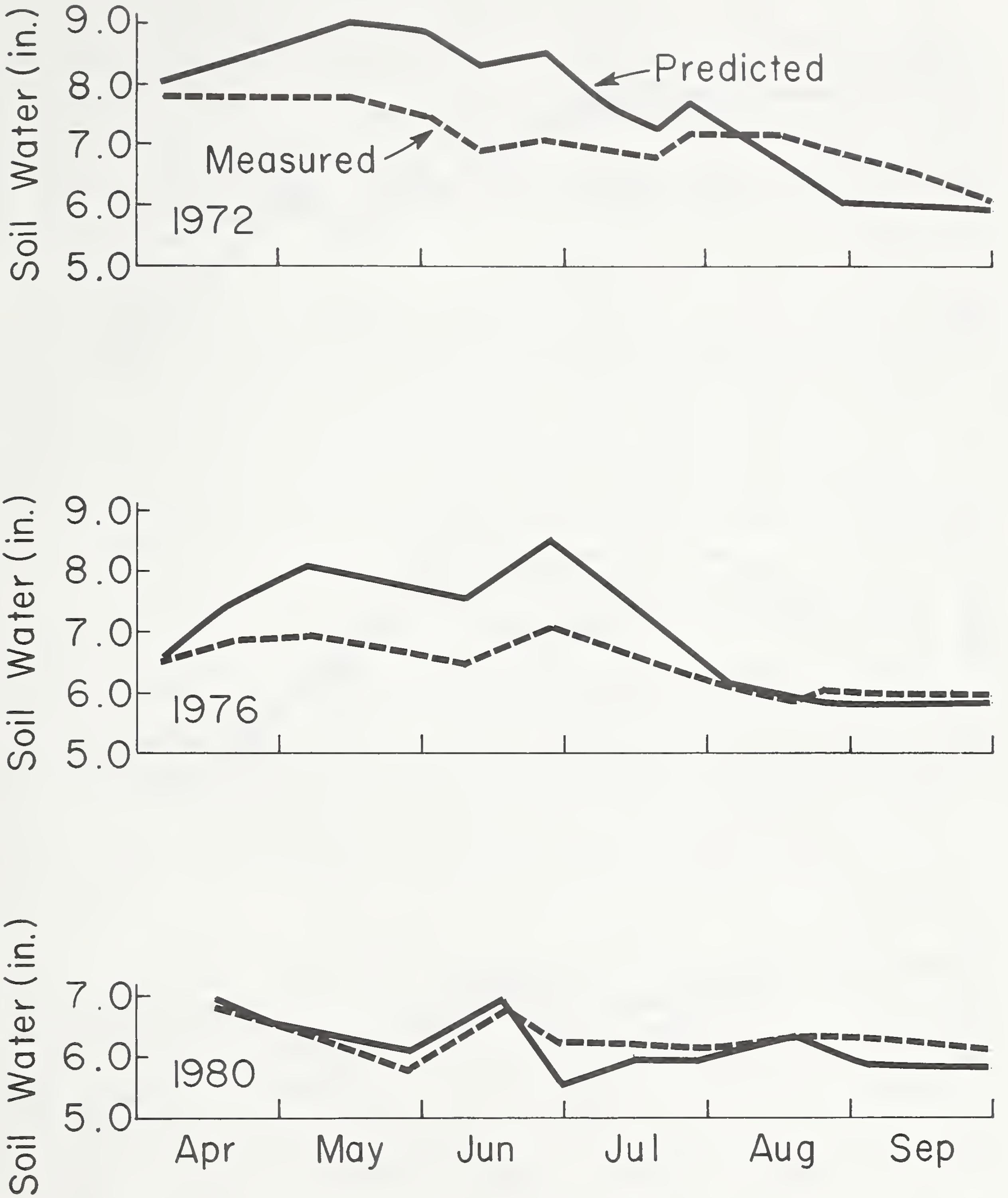

Figure 4.--Measured and predicted soil water (inches) in the top 2 feet of soil profile. Site 2, claypan range site, nonfurrowed watersheds, Ekalaka, Mont.

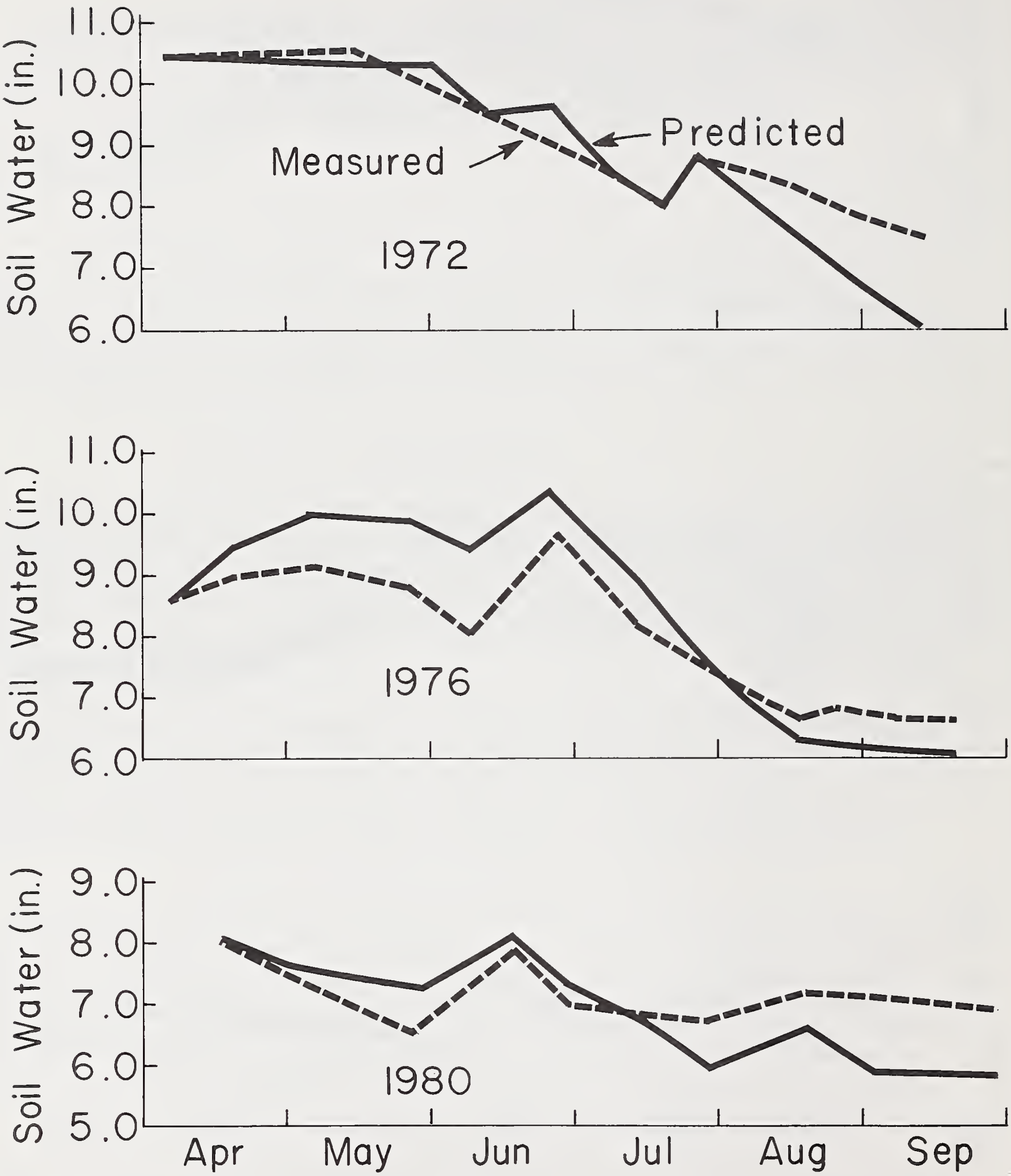

Figure 5.--Measured and predicted soil water (inches) in the top 2 feet of soil profile. Site 2, claypan range site, furrowed watersheds, Ekalaka, Mont.

the same, there would have been very little difference in the model-predicted and field-measured soil water. On the furrowed watersheds, the model allowed too much water to infiltrate into the second soil layer during years of above average precipitation. We suspect that the model underpredicted evaporation because it does not take into account evaporation from the free water surface of water impounded in the furrows. Such water may be present for several days following a precipitation event. Contour furrowing also increases the evaporation surface of the furrowed watersheds, resulting in more evaporation than the model predicts.

A comparison of the effects of tabular (table 7) with field- or laboratory-determined soil water parameters indicates that tabular values can be expected to provide effective estimates of these parameters (table 8). For site 1, the tabular value for field capacity was slightly below the estimated beginning soil water content, and the model would not run. By using an upwardly adjusted field capacity parameter with the explicit input option, the model would run, and there would be very little effect on the predicted yield or runoff. To obtain model-predicted soil water content that closely follows the field-measured values throughout the growing season, the soil water parameters, including beginning soil water content, need to be more accurate than those needed for yield and runoff predictions.

Sensitivity Analyses

The sensitivity of ERHYM to input parameters, as measured by predicted yield and runoff, varied among parameters and among years (tables 9 and 10). Predicted yield was most sensitive to beginning soil water content, especially for dry growing seasons, such as 1980. Predicted yields also showed some sensitivity to CROPCO and CN during above average precipitation growing seasons, but not during below average precipitation growing seasons. Runoff, as would be expected, was most sensitive to the CN, but was also somewhat sensitive to beginning soil water content and to CROPCO during relatively wet years. For yield and runoff, the model was least sensitive to the airdry factor (AIRDRY) and TRANCO.

In terms of practical application, good estimates of beginning soil water and the tabular soil water parameters will provide reasonably accurate yield predictions. Predicted runoff is controlled largely by the CN parameter, but is also sensitive to beginning soil water inputs. While the model was somewhat sensitive to CROPCO, this parameter should be relatively constant over a fairly wide range of vegetation types. A specific CROPCO can best be evaluated in terms of the daily water balance.

Herbage Yield Forecasting

The model includes a forecasting procedure developed by Wight and Hanson (*1982*) that utilizes historical climatic data. A population of site specific annual yield indices is generated using the current year's (forecast year) beginning soil water content and historical daily precipitation and temperature data for the remainder of the growing season. Each year of historical data

generates a yield index value. The generated populations of yield indices are usually normally distributed, and population means and standard deviations can be calculated and used to make probability forecasts. Forecasts can be periodically updated throughout the growing season by utilizing the current year's daily precipitation and mean temperature data up to the date of forecast and historical data for the remainder of the growing season. A similar procedure could be used to forecast runoff.

MODEL OPERATION

The information in this section identifies the parameters and data needed to run the model and describes their input format. A set of sample data is included with its associated output (table 11). As indicated in table 11, the model can plot the RGC. The model is programmed in FORTRAN IV and requires about 30,000 bytes of memory. Current versions of the model are running on Honeywell and Digital Equipment Corporation computers. When running real-time or on a growing season basis, the soil water boundary conditions are input at the beginning of each year's run.

Input Parameters

Input parameters for this model are readily obtainable from soil surveys, field observations, and included tables. Input of the soil texture code (table 7) will cause the model to assign the appropriate values for bulk density, permanent wilting, and field capacity for each horizon, plus AIRDRY.

All numeric input formats consist of 8 column fields unless specifically stated otherwise in the card description (see table 11). Integers are read with I8 formats, and real numbers are read with F8.0 formats. Integers must be right justified in columns 1 to 8, 9 to 16, 17 to 24, ... 73 to 80. Real numbers must be contained within the same columns, and the decimal point must be entered in the number. If the number has a decimal in it, the parameter is real; otherwise, it is an integer. The alphanumeric input is read with A4 formats. Specific instructions are given whenever alphanumeric input is required.

Card 1 TITLE
- TITLE - 1 line containing 48 characters of alphanumeric information to be printed at the beginning of the output.
- Format (12A4, 32X).

Card 2 OPTIONS
- RUNOPT
  - 1 - Forecast mode.
  - 1 - Simulate a single year's growing season. Set SHISD and FYEAR (card 3) to 0.
  - 2 - Continuous simulation over more than 1 year. Set SHISD and FYEAR (card 3) to 0.
- INOPT
  - 1 - Tabular values of soil characteristics.
  - 2 - Explicit soil characteristic values. If option 2 is selected, insert four additional cards after card 5.

WIDOPT 1 - 80-column printout.
2 - 132-column printout.

LOPT 1 - Inputs and outputs are in centimeters.
2 - Inputs and outputs are in inches.
3 - Precipitation input is in inches, and other inputs and outputs are in centimeters.

DAYOPT 1 - Daily printout.
2 - Printout only on days with precipitation.
3 - Yearly summary printout only.

CUROPT 1 - Relative growth curve plot not printed.
2 - Relative growth curve plot printed.

INTLEN - Number of days between subtotal printouts. If no subtotal printouts are wanted, set to 0.

TTDLEN - Number of days between total-to-date printouts. For only a seasonal or yearly printout, set to 0.

Card 3 STARTY, ENDY, STRDAY, ENDDAY, SHISD, FYEAR

STARTY - The last two digits of the first year of this run, for example, 72.

ENDY - The last two digits of the last year of this run, for example, 79.

STRDAY - Julian day of the first day of the model run, for example, 74.

ENDDAY - Julian day of the last day of the model run, for example, 180.

SHISD - Julian day the model starts using historical climatic data in the forecast mode, for example, 91. Set to 0 for other options.

FYEAR - The last two digits of the forecast year, for example, 81. Set to 0 for other options.

Card 4 FURCAP, SLARES, SOILT (one value per soil layer)

FURCAP - Surface storage capacity of the contour furrows, for example, 1.41.

SLARES - Number of soil layers, for example, genetic soil horizons with active roots present. Maximum of four.

SOILT - Numeric code for the type of soil in each layer. See table 6 for list of codes and soil types. Leave blank or set to 0 if the explicit soil characteristic values option (option 2 - INOPT) is selected.

Card 5 THK (one value per soil layer)

THK - Thickness of each soil layer. If LOPT (card 2) equals 1 or 3, then these values are assumed to be in centimeters. If LOPT equals 2, then these values are assumed to be in inches. If surface soil layer exceeds 12 inches (30.5 cm), it should be divided and entered as two equal soil layers.

(For option 2 under INOPT, card 2)

Card A MHC (one value per soil layer)
- Soil water content by weight (decimal fraction) at field capacity for each soil layer, for example, 0.35.

Card B UNASM (one value per soil layer)
- Soil water content by weight (decimal fraction) at permanent wilting for each soil layer, for example, 0.15.

Card C BULKD (one value per soil layer)
- The bulk density (grams per cubic centimeter) of each soil layer, for example, 1.3.

Card D AIRDRY (one value in the same units as THK, card 5)
- The amount of soil water below permanent wilting that can be evaporated, for example, 1.0.

Card 6 INITSM (one value per soil layer)
- The initial soil water content by weight (decimal fraction) for each soil layer, for example, 0.27.

Card 7 CROPCO, TRANCO, STRGRO, PSCDAY, ENDGRO, YIBASE, CSHAPE, DSHAPE
- CROPCO - Crop coefficient, for example, 0.85.
- TRANCO - Transpiration coefficient. Estimated from equation [13].
- STRGRO - Julian day that the growing season begins (RGC becomes greater than 0.0, for example, 91).
- PSCDAY - Julian day of peak standing crop, for example, 180.
- ENDGRO - Julian day growing season ends (RGC becomes 0.0).
- YIBASE - Set to 1.5 to calculate the yield index as a decimal fraction of the long-term average site yield; set to 1.0 to calculate the yield index as a decimal fraction of the potential site yield.
- CSHAPE - A shape parameter for left side of RGC, for example, 2.0 (see fig. 2).
- DSHAPE - A shape parameter for right side of RGC, for example, 2.0 (see fig. 2).

Card 8 DACRE, CS, LW, CN2, SIA
- DACRE - Fields are in acres, for example, 3.2.
- CS - Channel slope (ft/ft), for example, 0.022.
- LW - Watershed length width ratio calculated by squaring length and dividing by watershed area, for example, 2.1.
- CN2 - Condition II SCS curve number, for example, 80.0 (can never be less than 15).
- SIA - Initial abstraction coefficient for SCS curve number, usually 0.20 (always input in inches).

Climatic Data

Climatic data requirements include daily precipitation, solar radiation, and mean temperature. Daily solar radiation values are generated from a regression equation developed from eastern Montana solar radiation values. Daily precipitation and mean temperature data are available from weather station records. Long-term simulation can be accomplished through use of historical climatic records. Such records are available on magnetic tape for numerous Montana weather stations for the period 1917-71. As good stochastic climatic models become available, they can be readily added to the model to generate the necessary climatic data.

A data file containing climatic data for each day of the simulation period is required. If the model is used in the forecast mode, an additional climatic data file is required, which contains historical weather data for several years.

Both of these data files follow the same format. Each record contains 1 day's data, and the records are arranged in ascending order by date. Every record contains the year, the Julian day, maximum daily temperature, minimum daily temperature, and daily precipitation in the format (6X,I2,I3,X,2F3.0,F4.2) (table 11).

Model Output

Three options are available for model output: (1) daily printout with subtotals and cumulative to date for desired intervals (table 11); (2) printout on only the days precipitation occurred; or (3) printout of seasonal or yearly summaries only. These three options can be output in either an 80- or 120-column format. The 120-column output contains more information relative to the various components of the water budget. Discrepancies among interval and total-to-date summaries and daily output values are due to rounding errors.

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APPENDIX

Tables

Table 1.--*Annual and monthly runoff model test results (from Smith and Williams* 1980)

Watershed	Location	Drainage area	Length of record	Average measured P	Average measured Q	Annual predicted Q	Annual predicted ET	Annual predicted Percolation	Monthly R^2
		Square miles	*Years*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	
SW-2	Riesel, Tex.	0.004	4	36.94	6.28	7.73	27.82	1.14	0.75
SW-12	Do.	.005	9	38.08	9.05	6.45	30.63	1.05	.72
Y-6	Do.	.025	9	38.08	5.72	7.34	30.10	.80	.86
Y-8	Do.	.032	9	38.08	6.72	6.14	31.22	.68	.65
21-H	Hastings, Nebr.	.006	13	22.83	3.40	3.69	19.16	.03	.41
3-H	Do.	.006	14	23.25	5.22	5.31	18.03	.01	.66
3-H	Do.	.006	9	23.45	4.75	5.41	17.98	.01	.68
P-1	Watkinsville, Ga.	.010	3	47.54	8.72	8.30	33.03	6.95	.46
P-2	Do.	.005	2	44.26	5.94	6.46	29.15	9.30	.53
104	Coshocton, Ohio	.002	8	38.04	.35	.61	32.39	4.75	.39
104	Do.	.002	4	35.40	.88	1.14	28.67	4.73	.92
129	Do.	.004	34	35.73	.83	.84	29.81	5.15	.33
130	Do.	.003	33	35.50	.95	.84	30.58	4.18	.45
132	Do.	.001	21	35.32	2.08	2.18	28.70	4.57	.51
115	Do.	.003	30	37.07	1.93	2.33	31.22	3.53	.56
110	Do.	.002	29	35.38	1.70	1.78	30.81	2.76	.43
118	Do.	.003	33	36.53	2.01	2.23	30.95	3.35	.53
106	Do.	.002	31	34.60	2.06	1.73	30.21	2.63	.33
192	Do.	.012	28	34.71	2.61	1.88	30.19	2.87	.48
R-5	Chickasha, Okla.	.037	8	30.14	1.76	1.95	27.31	.70	.73
R-7	Do.	.030	8	30.14	5.98	5.30	24.19	.41	.86
C-4	Do.	.047	9	32.21	3.45	2.79	29.33	.10	.59
C-5	Do.	.020	9	27.46	2.02	1.92	25.32	.09	.35
W-6	Cherokee, Okla.	.003	19	23.74	3.33	3.58	20.05	.17	.45
W-7	Do.	.003	19	23.74	3.59	3.59	20.03	.17	.53
W-13	Do.	.003	7	21.79	1.66	2.11	19.56	.02	.59
W-2	Guthrie, Okla.	.005	10	28.00	4.18	3.74	23.34	1.17	.85
W-1	Do.	.004	7	27.41	.67	.89	25.54	1.57	.46
W-2	Vega, Tex.	.150	5	18.54	.97	.80	17.91	0	.27
W-1	Spur, Tex.	.018	19	20.07	1.93	2.05	18.03	0	.67
W-2	Do.	.015	19	20.07	2.68	2.56	17.51	0	.70
W-3	Do.	.018	18	20.10	1.55	1.72	18.35	0	.72
63105	Lucky Hills, Ariz.	.001	10	11.15	1.14	1.00	10.32	0	.84
01	Ft. Stanton, N. Mex.	.038	10	14.40	.02	.05	14.96	0	.24
02	Do.	.050	10	14.64	0	.06	14.94	0	
66001	Moorefield, W. Va.	.013	9	30.16	2.90	2.77	25.95	.93	.51
62014	Holly Springs, Miss.	.002	3	45.46	15.08	15.98	27.95	1.82	.80
62015	Do.	.002	3	33.73	9.48	9.65	24.22	1.19	.65

Table 1.--*Annual and monthly runoff model test results (from Smith and Williams* 1980*)--Continued*

Watershed	Location	Drainage area	Length of record	Average measured P	Average measured Q	Annual predicted Q	Annual predicted ET	Annual predicted Percolation	Monthly R^2
		Square miles	*Years*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	
22003	Guthrie Center, Iowa	.019	4	24.31	1.16	1.10	22.59	0.28	0.74
Z	Tifton, Ga.	.001	6	50.65	2.96	3.04	41.25	7.17	.26
A	Sidney, Mont.	.003	3	14.50	1.70	1.32	13.65	0	.72
W-3	Garland, Tex.	.016	8	41.02	9.14	8.92	30.66	.86	.84
W-1	Do.	.039	8	42.24	5.11	6.42	31.68	3.50	.86
W-3	Tyler, Tex.	.012	9	42.35	1.31	1.79	31.93	8.20	.36
W-5	Do.	.003	9	41.56	8.23	7.25	30.90	3.52	.58
W-4	Do.	.093	11	41.03	7.63	6.90	30.32	3.52	.60

Note: P = daily rainfall, Q = daily runoff, ET = evapotranspiration, and R^2 = coefficient of determination for measured and predicted runoff.

Table 2.--*Runoff model test results (events) (from Smith and Williams* 1980*)*

Watershed	Location	R^2	Runoff volume: Standard deviation: Measured	Runoff volume: Standard deviation: Predicted	Peak runoff rate: Mean: Measured	Peak runoff rate: Mean: Predicted	Peak runoff rate: Standard deviation: Measured	Peak runoff rate: Standard deviation: Predicted
SW-2	Riesel, Tex.	0.85	0.74	0.74	2.16	1.74	3.12	2.39
SW-12	Do.	.69	.74	.55	1.72	1.46	2.53	2.34
Y-6	Do.	.90	.68	.84	5.34	5.36	7.48	8.78
Y-8	Do.	.64	.64	.50	5.90	5.76	8.76	8.29
21-H	Hastings, Nebr.	.46	.42	.37	1.88	1.37	2.66	2.23
3-H	Do.	.65	.47	.41	3.06	1.51	4.05	2.45
3-H	Do.	.55	.55	.56	3.06	2.96	4.05	4.64
P-1	Watkinsville, Ga.	.60	.61	.48	4.47	3.01	6.72	4.94
P-2	Do.	.64	.45	.44	1.88	1.48	2.63	2.49
104	Coshocton, Ohio	.28	.10	.11	.48	.28	.75	.43
104	Do.	.88	.42	.36	.48	.45	.75	1.09
129	Do.	.24	.25	.17	.57	.67	1.05	1.30
130	Do.	.29	.26	.16	.33	.33	.74	.58
132	Do.	.46	.33	.24	.08	.09	.11	.16
115	Do.	.55	.32	.29	.73	.57	1.31	1.16
110	Do.	.37	.32	.23	.34	.45	.82	.86
118	Do.	.52	.29	.23	.59	.60	1.10	1.02
106	Do.	.31	.22	.19	.54	.49	1.15	.87
192	Do.	.41	.37	.25	1.05	1.24	2.88	2.41
R-5	Chickasha, Okla.	.72	.35	.32	5.69	5.39	9.99	8.15
R-7	Do.	.86	.45	.44	7.65	6.59	11.50	10.81
C-4	Do.	.64	.42	.36	3.75	1.69	3.74	2.75
C-5	Do.	.46	.32	.29	1.45	1.07	1.48	2.00
W-6	Cherokee, Okla.	.35	.44	.41	1.32	1.48	1.68	2.28
W-7	Do.	.42	.49	.42	1.48	1.35	1.87	2.09
W-13	Do.	.59	.31	.33	1.33	1.21	1.74	1.95
W-2	Guthrie, Okla.	.67	.38	.36	1.65	1.61	2.45	2.09
W-I	Do.	.15	.22	.15	.44	.75	.55	.89
63105	Lucky Hills, Ariz.	.64	.23	.17	.29	.13	.46	.20
01	Ft. Stanton, N. Mex.	0	.02	.12	1.43	1.84	1.03	2.23
02	Do.	.10	0	.13	1.00	1.49	.36	2.49
66001	Moorefield, W. Va.	.71	.70	1.54	.48	.64	.44	1.11
62014	Holly Springs, Miss.	.82	.74	.64	.89	1.39	1.21	1.65
62015	Do.	.62	.57	.50	.89	1.00	1.21	1.39
22003	Guthrie Center, Iowa	.44	.16	.17	.63	.95	.28	1.28
Z	Tifton, Ga.	.08	.23	.23	.48	.61	.54	.77
A	Sidney, Mont.	.68	.34	.28	.48	.38	.88	.59

Note: R^2 = coefficient of determination for measured and predicted runoff for individual events.

Table 3.--*Runoff curve numbers for range sites for the normal antecedent moisture condition, which is generally antecedent moisture condition II*[1] *(from Hanson et al.* 1981*)*

Range site	Range condition: Fair	Range condition: High-fair and good	Range condition: Excellent
Wetland	95	95	95
Very shallow	95	90	85
Saline subirrigated	90	90	85
Subirrigated	90	90	85
Shale	90	85	80
Dense clay	90	85	80
Alkali clay	90	85	80
Saline upland [2]	90	85	80
Igneous	90	80	75
Shallow clayey [2]	85	80	75
Shallow sandy	80	75	70
Shallow loamy [2]	80	75	70
Thin claypan [3]	80	75	70
Shallow igneous	80	75	70
Steep clayey	80	75	70
Clayey [2]	80	75	65
Gravelly loamy	80	75	65
Steep Loamy	80	75	65
Overflow	80	70	60
Loamy overflow	80	70	60
Clayey overflow	80	70	60
Coarse upland	80	70	60
Limy upland	80	70	60
Shallow breaks	80	70	60
Stony	80	70	60
Steep stony	80	70	60
Lowland	80	70	60
Saline lowland	80	70	60
Loamy lowland	80	65	55
Loamy	80	65	55
Sandy lowland	75	60	50
Sandy [2]	75	60	50
Gravelly	70	55	45
Sands	70	55	40
Choppy sands	70	55	40

[1]See USDA, Soil Conservation Service (*1978*).

[2]Range sites that were listed in USDA, Soil Conservation Service (*1978*) and were verified using watershed data from table 4.

[3]This range site was not included in the Wyoming table. This is a South Dakota SCS range site designation.

Table 4.--*Watershed location, area soil association, range site, range condition, hydrologic group, and SCS curve numbers (from Hanson et al. 1981)*

Watershed	Location	Area	Soil association	Range site	Range condition	Hydrologic group[1]	CN Low	CN Optimized	CN High	Record length	Number of events
		Hectares								*Years*	
EKA-1	Ekalaka, Mont.	0.81	Neldore	Saline upland	Low fair	D	86	93	99	7	13
EKA-2	Do.	.81	Gerdrum-Tealette	Saline upland[2] (panspots)	Fair	D	82	87	98	7	9
EKA-3	Do.	.81	--do--	--do--	--do--	D	80	89	97	7	7
AL-1	Aladdin, Wyo.	3.12	Pierre-Kyle	Shallow loamy	Good	D	67	83	89	4	6
AL-2	Do.	3.32	--do--	--do--	--do--	D	67	83	89	4	6
AL-3	Do.	4.69	--do--	Shallow clayey	--do--	D	72	79	91	4	7
AL-4	Do.	1.01	--do--	--do--	High fair	D	72	79	91	4	7
COT-4	Cottonwood, S. Dak.	3.47	Kyle	Clayey	Fair	D	55	73	89	10	11
COT-5	Do.	3.47	--do--	--do--	High fair	D	57	72	94	10	11
COT-6	Do.	3.64	--do--	--do--	Good	D	54	72	88	10	8
NEW-S1	Newell, S. Dak.	3.20	Twilight-Absher	Sandy	High fair	B	52	61	79	10	8
NEW-S3	Do.	4.57	--do--	--do--	Good	B	57	65	86	10	9
NEW-S5	Do.	6.68	--do--	--do--	--do--	B	45	50	85	10	6
NEW-P5	Do.	3.24	--do--	Thin claypan[3] (slickspots)	--do--	D	64	76	96	10	20
NEW-P6	Do.	5.34	--do--	--do--	--do--	D	64	74	90	10	11
NEW-P7	Do.	2.93	--do--	--do--	Fair	D	74	82	97	9	14
NEW-P8	Do.	2.60	--do--	--do--	--do--	D	75	82	91	9	13
NEW-P9	Do.	2.82	--do--	--do--	--do--	D	71	82	95	9	17
NEW-2	Do.	46.50	--do--	Mixed range sites[4] (silty, shallow sandy)	--do--	B	52	70	89	15	16
NEW-5	Do.	18.60	--do--	Mixed range sites [sandy, thin claypan (slick-spots), shallow sandy]	Good	B	50	61	94	15	15
NEW-7	Do.	64.70	--do--	--do--	High fair	B	55	63	93	15	13
NEW-12	Do.	36.40	Winler-Limas	Mixed range sites (shallow dense clay, dense clay)	Low fair	D	71	89	98	15	28
NEW-13	Do.	64.70	Pierre-Kyle	Mixed range sites (clayey)	Fair	D	64	85	96	15	17

Table 4.--*Watershed location, area soil association, range site, range condition, hydrologic group, and SCS curve numbers (from Hanson et al.* 1981)--*Continued*

Watershed	Location	Area	Soil association	Range site	Range condition	Hydrologic group[1]	CN			Record length	Number of events
							Low	Optimized	High		
		Hectares								*Years*	
NEW-14	Newell, S. Dak.	14.20	Pierre-Kyle	Clayey	High fair	D	67	77	94	15	19
NEW-15	Do.	46.50	--do--	--do--	--do--	D	70	78	98	15	19

[1]USDA, SCS hydrologic soil groups (USDA, Soil Conservation Service *1972*).

[2]Montana range site classification.

[3]South Dakota range site classification.

[4]Major range sites on each mixed range site watershed.

Table 5.--*Comparison of model-predicted annual yield, rainfall runoff, and runoff events with field-measured values, Ekalaka, Mont., 1969-80*

		Check						Furrowed					
	Ppt[1]	Yield [2]		Runoff		Runoff events		Yield		Runoff		Runoff events	
		Model	Field	Model	Field	Model	Field	Model	Field	Model	Field	Model	Field
	Inches	*--Lb/acre--*		*---Inches---*		*---Number---*		*---Lb/acre--*		*---Inches---*		*---Number---*	
Site 1													
1969	9.40	54	142	1.49	1.39	13	9	232	186	0	0	0	0
1972	13.20	234	184	2.55	3.02	20	16	308	381	0	0	0	0
1975	17.60	355	285	8.50	8.65	31	25	459	406	1.54	4.05	2	7
1976	11.70	224	416	3.17	4.45	16	8	393	340	.30	.82	1	4
1980	5.30	54	164	.58	1.07	5	7	119	242	0	.07	0	1
Mean	11.44	184	238	3.26	3.72	17	13	302	311	.37	.99	1	2
Site 2													
1969	10.20	206	260	1.73	.99	12	8	812	584	0	0	0	0
1972	13.20	448	345	1.69	1.54	16	13	1068	912	0	0	0	0
1975	16.99	560	348	6.25	7.62	28	21	1068	815	1.50	3.03	3	5
1976	12.30	407	540	2.38	1.92	14	7	1004	1149	.18	0	1	0
1980	5.20	124	297	.31	.04	4	2	384	384	0	0	0	0
Mean	11.50	349	358	2.47	2.43	15	10	867	769	.34	.61	1	1
Site 3													
1969	8.90	120	228	1.02	.72	11	7	776	539	0	0	0	0
1972	13.00	214	295	1.24	1.54	15	9	997	852	0	0	0	0
1975	17.50	350	249	6.19	6.53	23	17	1097	703[3]	1.28	4.86	2	6
1976	11.00	214	238	2.16	2.23	12	6	867	1014	.26	1.09	2	3

Table 5.--*Comparison of model-predicted annual yield, rainfall runoff, and runoff events with field-measured values, Ekalaka, Mont., 1969-80--Continued*

		Check						Furrowed					
	Ppt[1]	Yield [2]		Runoff		Runoff events		Yield		Runoff		Runoff events	
		Model	Field	Model	Field	Model	Field	Model	Field	Model	Field	Model	Field
	Inches	--*Lb/acre*--		---*Inches*---		---*Number*---		---*Lb/acre*--		---*Inches*---		---*Number*---	
Site 3 1980	5.20	70	184	0.16	0	4	0	252	260	0	0	0	0
Mean	11.12	194	239	2.15	2.20	13	8	798	674	.31	1.19	1	2
Grand mean	11.35	242	278	2.63	2.78	15	10	656	585	.34	.93	1	2

[1]From start of growing season in April through October.

[2]Measured at peak standing; model-predicted yield determined July 15. Yield LSD's for sites 1, 2, and 3 are 95, 160, and 196 lb/acre, respectively. Differences between field-measured yields that are less than the associated LSD's are not measurably different at 90 percent probability level.

[3]Yield adjusted to exclude yellow sweetclover.

Table 6.--*Comparison of model-predicted and field-measured runoff on an individual event basis, Ekalaka, Mont., 1972*

		Site 1		Site 2		Site 3	
Month	Day	Model predicted	Field measured	Model predicted	Field measured	Model predicted	Field measured
		----------	----------	----------	*Inches*	----------	----------
4	22	0.14	0	0.02	[1]	0.01	0
4	30	.02	0	0	0	0	0
5	1	.03	.22	0	.19	0	.03
5	2	0	.15	0	.14	0	.06
5	4	.24	.19	.08	.06	.05	.10
5	5	0	0	0	.06	0	.04
5	8	.10	0	.02	.03	.01	0
5	9	.01	.13	0	.04	0	.10
5	10	.24	.13	.14	.28	.07	.38
5	11	.19	.28	.06	.25	.05	.34
5	12	.03	0	0	0	[1]	0
5	19	0	0	.04	0	0	0
5	21	.20	0	0	0	0	0
5	22	0	.02	.07	0	.02	0
5	25	0	0	.01	0	0	0
5	28	.33	.34	.28	.03	.21	0
6	9	[1]	0	.05	0	0	0
6	21	.03	.02	.06	0	.03	0
6	25	.03	.02	.01	0	.01	0
6	26	.19	.32	.08	.01	.05	0
6	27	0	.01	0	0	0	0
7	14	.02	0	0	0	0	0
7	18	.02	.04	0	0	.10	0
7	22	.54	.62	.56	.24	.47	.40
8	2	.10	.10	.06	0	0.04	0
8	3	.09	.37	.16	.20	.10	.09
10	5	0	.06	[1]	0	.03	0
Mean		2.55	3.02	1.70	1.53	1.25	1.54

[1]Trace.

Table 7.--*Field capacity, permanent wilting, bulk density, and airdry values as related to soil texture*

Texture	Computer code	Field capacity[1]		Permanent wilting[1]		Bulk density[1]	Airdry[2]
		Volumetric	Gravimetric	Volumetric	Gravimetric		
		g/cm³	*g/g*	*g/cm³*	*g/g*	*g/cm³*	*Inches*
Sand	020	0.091	0.061	0.033	0.022	1.49	0.34
Loamy sand	060	.125	.084	.055	.037	1.49	.40
Sandy loam	100	.207	.143	.095	.066	1.45	.48
Loam	130	.270	.190	.117	.082	1.42	.52
Silt loam	140	.330	.250	.133	.101	1.32	.56
Sandy clay loam	160	.255	.159	.148	.092	1.60	.60
Clay loam	170	.318	.224	.197	.139	1.42	.80
Silty clay loam	180	.366	.261	.208	.149	1.40	.83
Sandy clay	190	.337	.223	.239	.158	1.51	.92
Silty clay	200	.387	.280	.250	.181	1.38	1.00
Clay	210	.396	.285	.272	.196	1.39	1.00

[1]From Rawls et al. (*1982*).

[2]The amount of water in the top 12 inches of soil profile held at tensions greater than permanent wilting that can be removed by evaporation.

Table 8.--*Comparison of field-measured and model-predicted yields and runoff, using actual and tabular (table 7) soil parameter inputs, Ekalaka, Mont.*

Year and site	Yield: Model predicted: Tabular	Yield: Model predicted: Actual	Yield: Field measured	Runoff: Model predicted: Tabular	Runoff: Model predicted: Actual	Runoff: Field measured
	---*Lb/acre*---			---*Inches*---		
1972:						
Site 1	NR[1]	234	184	NR	2.55	3.02
Site 2	519	448	345	2.22	1.69	1.54
Site 3	148	214	295	1.25	1.24	1.54
1976:						
Site 1	NR	224	416	NR	3.17	4.45
Site 2	478	407	540	2.94	2.38	1.92
Site 3	183	214	238	2.33	2.16	2.23
1980:						
Site 1	NR	54	164	NR	.58	1.07
Site 2	214	124	297	.36	.31	.04
Site 3	12	70	184	.20	.16	0

[1]NR indicates that the model did not run. On site 1, the tabular field capacity was less than the beginning soil water content, and the model would not run.

Table 9.--*Sensitivity analyses: The effect of changes*[1] *in the airdry factor (AIRDRY), transpiration coefficient (TRANCO), crop coefficient (CROPCO), and SCS curve number (CN) parameters on model-predicted yield and runoff for a nonfurrowed claypan range site (site 2), Ekalaka, Mont., 1972, 1976, and 1980*

	1972		1976		1980	
	Yield	Runoff	Yield	Runoff	Yield	Runoff
	Lb/acre	*Inches*	*Lb/acre*	*Inches*	*Lb/acre*	*Inches*
AIRDRY (inches):						
0.39	449	1.70	407	2.38	147	0.44
0.78	449	1.70	407	2.38	130	.35
1.18	449	1.69	407	2.38	124	.28
TRANCO:						
0.1	466	1.69	408	2.35	136	.31
0.3	442	1.69	408	2.39	124	.31
0.5	437	1.72	413	2.44	124	.34
CROPCO:						
0.6	555	2.63	519	3.09	154	.36
0.8	478	1.84	413	2.12	124	.31
1.0	366	1.33	325	2.06	118	.30
CN:						
70	508	.42	478	1.05	124	.01
80	484	1.11	449	1.82	124	.12
90	384	2.58	325	3.12	124	.65

[1]AIRDRY, TRANCO, CROPCO, and CN were held constant at 0.98, 0.25, 0.85, and 85, respectively, except when they were the input parameter under consideration.

Table 10.--*Sensitivity analyses: The effects of 3 levels of beginning soil water content on model-predicted yield and runoff for 3 nonfurrowed range sites, Ekalaka, Mont., 1972 and 1980*

Year and site	Percent available water[1]					
	0	50	100	0	50	100
	------*Yield (lb/acre)*-----			------*Runoff (inches)*-------		
1972:						
Site 1	136	244	316	1.82	2.50	3.24
Site 2	277	525	590	1.21	2.06	3.52
Site 3	175	308	374	1.19	1.89	3.08
1980:						
Site 1	4	97	248	.57	.68	.92
Site 2	0	242	519	.28	.44	.72
Site 3	4	160	334	.14	.30	.52

[1]Beginning soil water content expressed as percent of the available water holding capacity.

Table 11.--Sample climatic data and an example of model output including the input parameter edit and specified growth curve. The climatic data and the input parameter edit data can be used as test data to check model operation

CLIMATIC DATA

YEAR	JDAY	MAX	MIN	PPT	YEAR	JDAY	MAX	MIN	PPT
76	163	89	60	0.10	76	180	76	43	0.00
76	164	74	45	0.30	76	181	74	42	0.00
76	165	65	45	0.60	76	182	79	55	0.00
76	166	63	47	1.70	76	183	82	57	0.00
76	167	71	42	0.00	76	184	82	57	0.60
76	168	67	45	0.30	76	185	79	55	0.00
76	169	62	55	0.30	76	186	81	56	0.00
76	170	63	50	0.00	76	187	82	65	0.00
76	171	78	55	0.00	76	188	86	58	0.00
76	172	75	50	0.00	76	189	87	58	0.00
76	173	78	50	0.00	76	190	88	61	0.00
76	174	75	56	1.40	76	191	90	64	0.00
76	175	74	55	0.10	76	192	90	61	0.00
76	176	65	46	0.00	76	193	90	67	0.00
76	177	63	48	0.10	76	194	91	66	0.00
76	178	63	38	0.00	76	195	90	53	0.10
76	179	72	41	0.00	76	196	83	51	0.00

Table 11.--Continued

E R H Y M INPUT PARAMETER EDIT

CARD	FIELD 1	2	3	4	5	6	7	8
1	***** EKALAKA SITE 2-NEW MODEL *****							
2	1	2	2	2	1	2	7	28
3	76	76	163	196	0	0	0	0
4	0	4	0					
5	12.	12.	12.	12.				
	***** INPUT OPTION 2 *****							
6	.320	.320	.320	.320				
7	.200	.200	.200	.200				
8	1.40	1.40	1.40	1.40				
9	.98							
10	.193	.205	.230	.230				
11	.85	.32	91	196	280	1.0	2.0	2.0
12	1.0	.050	2.0	85.0	.20			

***** NO ERRORS *****

Table 11.--Continued

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****************************************
****************************************
***                                  ***
***        E R H Y M   M O D E L     ***
***                                  ***
***           24-JUN-82              ***
***                                  ***
****************************************
****************************************
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***** EKALAKA SITE 2-NEW MODEL *****

RUN FOR 163/76 THROUGH 196/76

THE GROWING SEASON BEGINS ON DAY 91
AND ENDS ON DAY 280
YIELD INDEX BASED ON SITE POTENTIAL

S O I L   C H A R A C T E R I S T I C S

THERE ARE 4 SOIL LAYERS
WATER BELOW UNAVAILABLE SOIL MOISTURE AVAILABLE FOR EVAPORATION(IN) = 0.98
FURROW CAPACITY(IN) = 0.00

	SOIL LAYER 1	2	3	4	TOTAL
AVAILABLE SOIL WATER CAPACITY(IN)	2.02	2.02	2.02	2.02	8.1
UNAVAILABLE SOIL WATER(IN)	3.36	3.36	3.36	3.36	13.4
TOTAL SOIL WATER CAPACITY(IN)	5.38	5.38	5.38	5.38	21.5
INITIAL SOIL WATER CONTENT(IN)	3.24	3.44	3.86	3.86	14.4
THICKNESS(IN)	12.00	12.00	12.00	12.00	48.0

P L A N T   C H A R A C T E R I S T I C S

THE CROP COEFFICENT = 0.85
TRANSPIRATION COEFFICENT = 0.32

W A T E R S H E D   C H A R A C T E R I S T I C S

DRAINAGE AREA (ACRES) = 1.0
CHANNEL SLOPE = 0.05
LENGTH/WIDTH RATIO = 2.00
CONDITION 2 SCS CURVE NUMBER = 85
INITIAL ABSTRACTION COEFFICENT FOR SCS CURVE NUMBER METHOD = 0.20

Table 11.--Continued

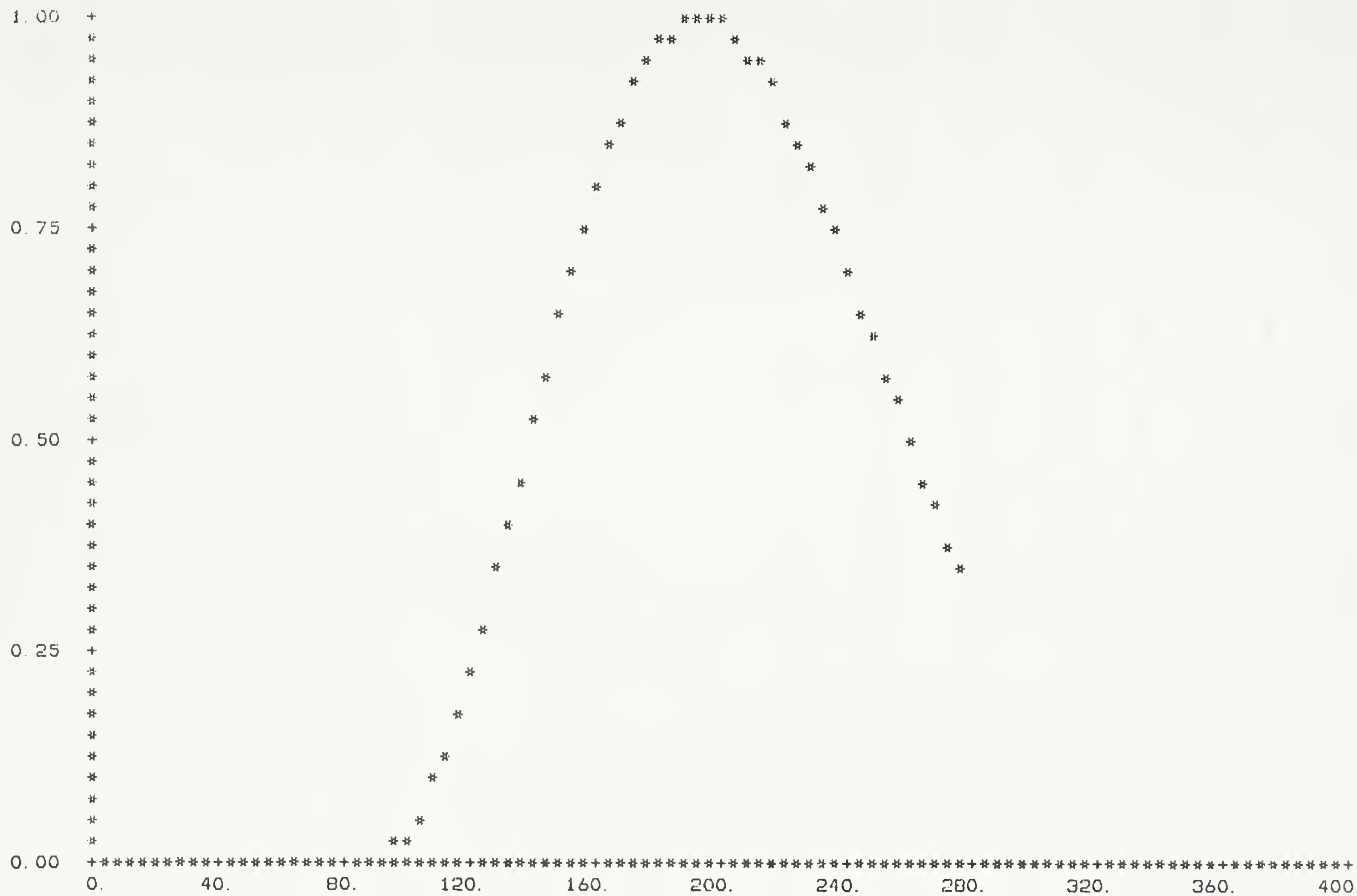

Table 11.--Continued

PAGE 1 ***** EKALAKA SITE 2-NEW MODEL ***** YEAR = 1976

DAY	EO	POTENTIAL EVAP	POTENTIAL TRAN	EVAP	ACTUAL TRAN, SOIL LAYER 1	2	3	4	PRECIP	SNOWP	DRAIN	RUNOFF	PEAKF	TOTAL SOIL WATER SOIL LAYER 1	2	3	4	ATN/PTN
163	0.24	0.13	0.07	0.10	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	3.2	3.4	3.9	3.9	0.11
164	0.16	0.09	0.05	0.09	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	3.4	3.4	3.9	3.9	0.16
165	0.14	0.08	0.04	0.08	0.01	0.00	0.00	0.00	0.60	0.00	0.00	0.05	0.28	3.9	3.4	3.9	3.9	0.39
166	0.14	0.08	0.04	0.08	0.03	0.00	0.00	0.00	1.70	0.00	0.00	0.78	4.27	4.7	3.4	3.9	3.9	0.80
167	0.15	0.08	0.04	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.6	3.4	3.9	3.9	0.76
168	0.15	0.08	0.04	0.08	0.03	0.00	0.00	0.00	0.30	0.00	0.00	0.02	0.09	4.8	3.4	3.9	3.9	0.85
169	0.16	0.09	0.04	0.09	0.04	0.00	0.00	0.00	0.30	0.00	0.00	0.02	0.12	5.0	3.4	3.8	3.8	0.94
163-169	0.16	0.64	0.32	0.58	0.13	0.00	0.02	0.02	3.30	0.00	0.00	0.87		1.7	0.0	0.0	0.0	0.53
170	0.15	0.08	0.04	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.9	3.4	3.8	3.8	0.89
171	0.20	0.11	0.06	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.8	3.4	3.8	3.8	0.85
172	0.18	0.10	0.05	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.7	3.4	3.8	3.8	0.81
173	0.19	0.11	0.05	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.6	3.4	3.8	3.8	0.77
174	0.19	0.11	0.05	0.11	0.05	0.00	0.00	0.00	1.40	0.00	0.00	0.71	3.86	5.1	3.4	3.8	3.8	1.00
175	0.19	0.11	0.05	0.10	0.05	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	5.1	3.4	3.8	3.8	1.00
176	0.14	0.08	0.04	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.0	3.4	3.8	3.8	0.98
170-176	0.18	0.70	0.35	0.48	0.27	0.01	0.02	0.02	1.50	0.00	0.00	0.71		0.0	0.0	0.0	0.0	0.90
177	0.14	0.08	0.04	0.08	0.03	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	5.0	3.4	3.8	3.8	0.98
178	0.12	0.07	0.03	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.9	3.4	3.8	3.8	0.94
179	0.15	0.09	0.04	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.8	3.4	3.8	3.8	0.91
180	0.16	0.09	0.04	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.8	3.4	3.8	3.8	0.87
181	0.16	0.09	0.04	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.7	3.4	3.8	3.8	0.84
182	0.20	0.12	0.05	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.6	3.4	3.8	3.8	0.81
183	0.21	0.12	0.06	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.5	3.4	3.8	3.8	0.77
177-183	0.16	0.66	0.31	0.36	0.22	0.01	0.02	0.02	0.10	0.00	0.00	0.00		-0.5	0.0	0.0	0.0	0.86
184	0.21	0.12	0.06	0.12	0.04	0.00	0.00	0.00	0.60	0.00	0.00	0.13	0.70	4.8	3.4	3.8	3.8	0.93
185	0.20	0.12	0.05	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.7	3.4	3.8	3.8	0.87
186	0.21	0.12	0.05	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.6	3.4	3.8	3.8	0.82
187	0.23	0.14	0.06	0.07	0.04	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	4.5	3.4	3.8	3.8	0.77
188	0.22	0.13	0.06	0.06	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	4.4	3.4	3.8	3.8	0.73
189	0.23	0.13	0.06	0.05	0.03	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	4.3	3.4	3.8	3.8	0.69
190	0.23	0.14	0.06	0.05	0.03	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	4.2	3.4	3.8	3.8	0.65
184-190	0.22	0.90	0.40	0.51	0.24	0.01	0.03	0.03	0.60	0.00	0.00	0.13		-0.3	0.0	0.0	0.0	0.78
TTD ON DAY 190	2.91	1.38	1.94		0.85	0.03	0.09	0.09	5.50	0.00	0.00	1.71		1.0	0.0	-0.1	-0.1	0.77
191	0.25	0.15	0.06	0.05	0.03	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	4.2	3.4	3.8	3.8	0.62
192	0.24	0.14	0.06	0.05	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	4.1	3.4	3.8	3.8	0.58
193	0.25	0.15	0.06	0.05	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	4.0	3.4	3.8	3.8	0.55
194	0.25	0.15	0.06	0.05	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	4.0	3.4	3.7	3.7	0.52
195	0.22	0.13	0.05	0.10	0.02	0.00	0.01	0.01	0.10	0.00	0.00	0.00	0.00	3.9	3.4	3.7	3.7	0.51
196	0.20	0.12	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.9	3.4	3.7	3.7	0.49
FINAL TOTAL		3.75	1.73	2.26	0.97	0.03	0.13	0.12	5.60	0.00	0.00	1.71		0.7	0.0	-0.1	-0.1	0.73

Symbols and Abbreviations

AW - available soil water storage capacity
CN - curve number
CN_I - moisture condition I CN
CN_{II} - moisture condition II CN
CROPCO - crop coefficient
CS - mainstem channel slope
DA - drainage area
D - soil layer thickness
E - actual soil evaporation
E_p - soil evaporation potential
ET - evapotranspiration
ET_p - evapotranspiration potential
ET_{pr} - evapotranspiration potential from rangeland
F - daily mean temperature in degrees Fahrenheit
M - daily snowmelt
P - daily rainfall
Q - daily runoff
q_p - peak runoff rate
RD - rooting depth
RGC - relative growth curve
ROOTF - root function
R_s - solar radiation
s - water retention parameter
SM - soil water content of root zone
SOILT - soil temperature in degrees Celsius
s_{mx} - maximum value of s
SWS - available soil water
t - time in days
T - actual transpiration
Temp - temperature in degrees Celsius
T_p - transpiration potential
TRANCO - transpiration coefficient
UL - upper limit of soil water storage

Symbols and Abbreviations--Continued

W - weighting factor

Y - annual herbage yield

Y_p - yield potential

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